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PHYSIOLOGICAL, BIOCHEMICAL, AND MULTIPLE-TASK-PERFORMANCE RESPONSES TO DIFFERENT ALTERATIONS OF THE WAKE-SLEEP CYCLE

E. A. Higgins
W. D. Chiles
J. M. McKenzie
G. E. Funkhouser
M. J. Burr
A. E. Jennings
J. A. Vaughan
Civil Aeromedical Institute
Federal Aviation Administration
Oklahoma City, Oklahoma

November 1976

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Federal Aviation Administration, Office of Aviation Medicine, Civil Aeromedical Institute, Oklahoma City, Oklahoma. **PHYSIOLOGICAL, BIOCHEMICAL, AND MULTIPLE-TASK-PERFORMANCE RESPONSES TO DIFFERENT ALTERATIONS OF THE WAKE-SLEEP CYCLE** by E. A. Higgins, W. D. Chiles, J. M. McKenzie, G. E. Funkhouser, M. J. Burr, A. E. Jennings, and J. A. Vaughan, November 1976, 20 pp. Report No. **FAA-AM-76-11.**

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16. Abstract

Three groups, each comprising five healthy, male, paid volunteers (ages 21 to 30), were studied for 11 days. Baseline data were collected for 3 days, during which subjects adhered to a day/night routine, i.e., sleeping from 2230 to 0600. On the fourth day each group took a "flight" in the altitude chamber. Following the flight day, subjects in the first group (Group I) slept from only 0230 to 0600; and then returned to the baseline routine; subjects in the next group (Group II) had their day extended by 6 hours and began a new routine of sleeping from 0430 to 1200 for the remainder of the study; subjects in the third group (Group III) had their day compressed by 6 hours and slept from 2030 to 2400 only that fourth night and then began a new routine of sleeping from 1630 to 2400 for the final 7 days of the study. According to the physiological and biochemical measurements, there was little difference between the two 6-hour-change groups (Groups II and III), both of which required longer rephasal times than did the group that experienced sleep loss but no time change (Group I). The psychomotor performance test indicated the greatest change in the group whose day was shortened by 6 hours (Group III). The Multiple Task Performance Battery (MTPB) indicated the greatest deficit in performance for Group III and the best postshift performance for Group II. Therefore, if performance of the type represented by the MTPB is the most important consideration, then travel from west to east (or "quick turnarounds" for shift workers) appears to be more deleterious than changes in the opposite direction. However, this effect cannot be predicted on the basis of the physiological and biochemical determinations made in this study.

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A

PHYSIOLOGICAL, BIOCHEMICAL, AND MULTIPLE-TASK-PERFORMANCE RESPONSES TO DIFFERENT ALTERATIONS OF THE WAKE-SLEEP CYCLE

I. Introduction.

Because rapid air transportation across time zones often necessitates a change in the traveler's wake-sleep cycle that consequently results in disruption of his biological rhythm patterns, and because rotating shift patterns are necessary to maintain 24-h service in many areas, the FAA has continued its interest in biorhythms, their changes as a result of altering the wake-sleep cycle, and their relationships with performance.

II. Material and Methods.

We previously conducted a study in which the wake-sleep cycle was altered by 12 h.[6] This current study was conducted in three phases. Three groups, each comprising five healthy, male, paid volunteers (ages 21 to 30), were studied in a laboratory setting. Because results of the 12-h study indicated that some of the effects seen were due to the long period of confinement in the laboratory, the data collection periods for this study were shortened to the minimum number of days consistent with obtaining the desired results. Each group first spent five 10-h days training on a psychomotor performance test (Kugelmaschine) and the CAMI Multiple Task Performance Battery (MTPB); a total of 15 h of training was given on the MTPB. This training period, which also provided an opportunity for subjects to become familiar with the laboratory setting and learn the experimental protocol, was followed by an 11-day data collection period. Baseline data were collected for 3 days, during which subjects adhered to a day/night routine; i.e., sleeping from 2230 to 0600. On the fourth day each group took a "flight" in the CAMI altitude chamber; time spent aboard was equivalent to that required for a flight from Oklahoma City to London with a change of planes at Chicago's O'Hare International Airport. Subjects in the first group (Group I) slept from only 0230 to 0600 on the fourth night and then returned to their former day/night routine, sleeping from 2230 to 0600 for the remaining 7 days. The next group of subjects (Group II) had their day extended by 6 h and began a new routine of sleeping from 0430 to 1200; they followed this new routine for 7 days. This is the timeframe that would be assumed after an east-to-west flight across six time zones. On the fourth day subjects in the last group (Group III) slept from 2030 to 2400 only and the following 7 days slept from 1630 to 2400; this routine compressed their day and established a new wake-sleep cycle that was 6 h earlier than the usual cycle. This timeframe corresponds to the timeframe following a west-to-east flight across six time zones.

Measurement of heart rate (HR) and internal body temperature (T_{re}) were made hourly throughout the study. Dry silver electrodes[11] attached in the CM_5 position were connected by wires to an Avionics Electrocardiocorder, and HR responses were recorded on electromagnetic tape. Tape and batteries were replaced each 24 h. Although HR was recorded continuously, only hourly average readings were statistically analyzed. Internal body temperature was measured with a thermistor probe inserted 10 cm beyond the anal sphincter. Values were read to the nearest 0.1°C with a portable bridge.

Urine was collected every 4 h throughout the experimental period. The volume was recorded; aliquots were taken, preserved with 1.2N HC1, and frozen for later biochemical analyses. Urinary catecholamines[4] and 17-ketogenic steroids[3] (17-KGS) were determined by using Technicon Autoanalyzer systems. Sodium (Na^+) and potassium (K^+) were measured with an atomic absorption-emission spectrophotometer (Instrumentation Laboratory, Inc., Model 353).

Subjective questionnaires included the 10-item Subjective Fatigue Checklist developed by Pearson and Byars[10] and a sleep survey developed at the USAF School of Aerospace Medicine that reflected the test subjects' judgment of both the length and quality of sleep the previous night.

Subjects were tested on the CAMI MTPB at 4-h intervals in 2-h sessions; both the first and second h of a session involved the task schedule shown in Table 1. The MTPB consists of five subject panels and the associated programing and scoring circuitry. Each panel contains the displays and response devices for six different tasks, each of which may be presented in isolation or in any combination of tasks. The tasks are described in more detail elsewhere;[1] therefore, only a brief description of each will be given here.

TABLE 1.—One-Hour Task Schedule for All Groups

	Time in Minutes			
	0-15	15-30	30-45	45-60
Lights Monitoring	X	X	X	X
Meter Monitoring	X	X	X	X
Arithmetic			X	X
Pattern Identification		X		
Problem Solving		X	X	
Tracking	X		X	

Warning Lights. The warning lights task involves monitoring of five green lights and five red lights. Under each light is a pushbutton switch. The green lights are normally on and the red lights are normally off; the subject is instructed to push the button under the light whenever a light changes state. Signals were introduced at random intervals with a mean intersignal interval of 30 s.

Meter Monitoring. The meter monitoring task involves monitoring of four meters mounted across the top of the subject panel. Normally, the meter pointers are moving at random around a mean vertical position. The subject responds to a shift in the mean position of the pointer by throwing the associated level switch in the direction of the deflection. The signals are introduced on randomly selected meters at randomly varying intervals, with a mean intersignal interval of 1 min.

Mental Arithmetic. In the mental arithmetic task, the subject is required to add two numbers and subtract a third number from the sum of the first two. The problem elements were between 10 and 99 and were selected with the restriction that neither digit of the third number should be identical to the corresponding digit of either of the first two numbers. The arithmetic task is machine paced; a new problem is presented every 20 s. Both response time and accuracy are measured on this task. Accuracy is determined as a percentage of all problems presented.

Pattern Identification. The display for the pattern identification task is a screen on the lower left of the subject's panel. This screen consists of a six-by-six matrix of close-butted lights covered by a translucent panel. A standard pattern and two comparison patterns are presented to the subject in succession. He must then decide if one, neither, or both of the comparison patterns are the same as the standard (first) pattern and indicate his answer by pressing the appropriate response button. Pattern-identification problems are presented at the rate of 1 every 30 s. Both accuracy and response time are kept on this task.

Group Problem Solving. The group problem-solving task involves short-term memory and skill at following a set procedure. Each subject has a single pushbutton switch and three feedback lights mounted in the center of his panel. In this study, the five subjects in each group worked together to discover the correct sequence in which to push these buttons. Each problem sequence is presented twice in succession. In the first presentation, the solution phase, the subjects must determine the solution sequence by following a standard trial-and-error search sequence. In the second presentation, or confirmation phase, the subjects reenter the previous solution from memory. Response times are recorded separately for the solution and confirmation phases. Response time is measured from the previous problem-solving event, either a problem introduction or a button push. In addition, accuracy in the confirmation phase is recorded as the proportion of correct to total responses.

Two-Dimensional Compensatory Tracking. The display for the tracking task is an oscilloscope screen situated on top of the subject's panel. The target on the screen is a dot of light about 1 mm in diameter. A random movement is imparted to the target, and the subject attempts to counteract this movement by using his control stick to keep the dot at the center of the screen (as defined by two crosshairs scribed on the face of the screen). The tracking task is scored by analog circuitry that accumulates integrated absolute error and integrated error-squared measures for the horizontal and vertical dimensions. Root-mean-square error is computed from the error-squared measures, and a vector sum measure is computed by taking the square root of the sum of the measures of horizontal and vertical error squared. The rationale for using this vector sum score is that the integrated error measures represent average horizontal and vertical distance from the center of the screen. Therefore, the vector sum of these distances would represent the hypotenuse of the triangle defined by these horizontal and vertical distances.

In the analyses performed on the MTPB data, the measure used was an equal-variance composite score that was computed as follows: For each measure, an appropriate equation was derived by using the data for the 3 days prior to the shift. The equation was developed in a manner such that the mean score for each subject was 500 with a standard deviation of 100 for those 3 days combined (time scores were "reflected" so that a larger score meant better performance). The raw scores for a given measure taken during the postshift phase of the experiment were entered into the associated equation to get a derived measure, and the derived measures were then combined across tasks. The resultant composite score gave equal weight to each of the original measures. The composites also tended to equalize the three groups as regards the initial values of the scores. Hence, the interpretation of the scores is properly made in relation to the 3 days prior to the shift.

The Kugel test estimated psychomotor performance. The "Kugelmaschine" was a horizontal rotating cylinder containing a row of five holes of graded sizes. Three sets of five steel balls corresponding in size to the holes in the cylinder were placed in a tray attached to the machine near the base of the cylinder. The test subject, seated in front of the tray, was instructed to pick up and insert as rapidly as possible the correct ball into a corresponding row of stationary holes lined up with those of the rotating cylinder. The cylinder rotated at 80 holes per min. Each test session was 10 min in duration for a total possible score of 800. Each correct selection was recorded on an attached counter.

A schedule of events showing the time and frequency of occurrence is presented in Figure 1.

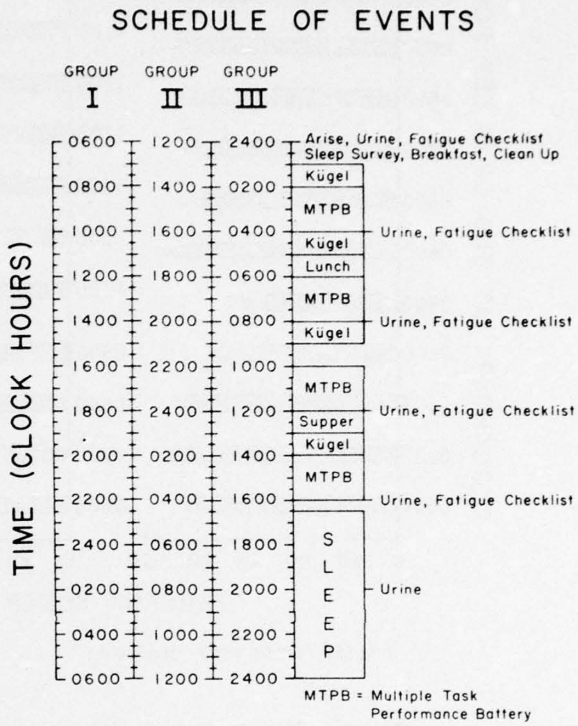

FIGURE 1.—Schedule of events.

All groups followed the schedule shown for Group I during the first 3 days of the experiment. Each group followed the schedule as indicated by group number for the last 7 days of data collection.

III. Results.

Subjective Forms. Figure 2 presents a bar graph for the three groups, indicating the percentage of the sleep periods they were asleep. Table 2 presents the sleep data as it pertains to the quality of sleep. For each group is presented the total time asleep (percentage), the percentage of the sleep period spent in moderate or deep sleep, and the percentage of the sleep period spent awake or in light sleep. During the control period (night sleep), Group I slept 81.3 percent of the time available, Group II slept 85.6 percent of their sleep periods, and Group

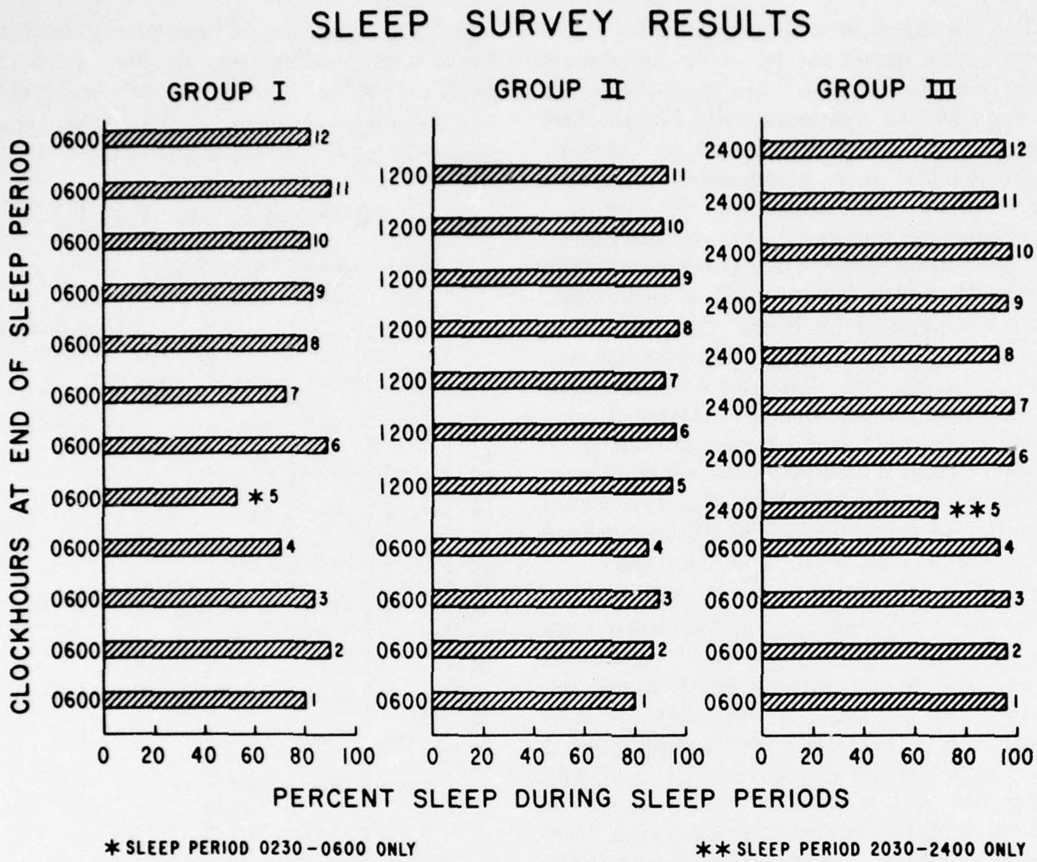

FIGURE 2.—Mean scores from Sleep Survey for Groups I, II, and III (n=5 for each group).

III slept 95.6 percent of the time available for sleep. After the change in their routine, Group II increased their percentage of sleep significantly, averaging 94.2 percent of the sleep time the first 3 days after the change and 94.1 percent for the last 3 days of the experiment. Group III, which reported the greatest sleep percentage, demonstrated little change in their time asleep, sleeping 96.9 percent of the sleep periods the first 3 days after the change and 96.0 percent for the last 3 days of the experiment. Group I demonstrated no change for the first 3 days after the "flight" day (81.3 percent) and a small increase (85.3 percent) for the final 3 days. Groups I and III demonstrated rather low percentages of sleep (53.4 and 55.0 percent respectively) during their short (3½-h) sleep segments on the day of the change.

A graph of results of the Subjective Fatigue Indices is presented in Figure 3. The daily averages for each group are listed in Table 3. The daily averages for the control group (Group I) demonstrate the least variability, ranging from 8.6 to 10.9 (lower scores indicate greater rated fatigue). Their greatest fatigue was indicated for the last day of the experiment. Group II indicated their greatest feelings of fatigue during the middle of the postshift period. Group III indicated their greatest fatigue the first day after the change in the wake-sleep cycle.

Physiological and Biochemical Responses. The physiological and biochemical data were collected at regular time intervals throughout the experimental period. This schedule allowed treatment of the data by Fourier analysis and determination of the 24-h time of peak response. The 24-h peak-response data were subsequently prepared in summation-dial format,[5] which is a vectorial representation of the time of peak re-

Table 2.—Results of Sleep Survey

Sleep Period Number	Group I Total Time Asleep (%)	Group I Moderate or Deep Sleep (%)	Group I Awake or Light Sleep (%)	Group II Total Time Asleep (%)	Group II Moderate or Deep Sleep (%)	Group II Awake or Light Sleep (%)	Group III Total Time Asleep (%)	Group III Moderate or Deep Sleep (%)	Group III Awake or Light Sleep (%)
1	80.0	69.6	30.4	80.0	72.0	28.0	96.0	61.4	38.6
2	90.4	62.6	37.4	87.8	66.8	33.2	96.0	72.0	28.0
3	84.0	69.2	30.8	89.4	82.6	17.4	97.3	70.7	29.3
4	70.8	58.0	42.0	85.4	78.4	21.6	93.3	77.3	22.7
*	53.4	48.0	52.0	-	-	-	55.0	27.5	72.5
5	89.2	78.6	21.4	94.6	73.2	26.8	98.7	81.3	18.7
6	73.4	60.0	40.0	96.0	73.2	26.8	98.7	89.3	10.7
7	81.4	68.0	32.0	92.0	89.2	10.8	93.3	77.3	22.7
8	84.0	74.6	25.4	97.2	73.4	26.6	97.3	72.0	28.0
9	82.6	72.0	28.0	97.2	89.2	10.8	98.7	86.7	13.3
10	90.6	80.0	20.0	91.8	90.6	9.4	93.3	78.7	21.3
11	82.6	74.4	25.6	93.2	86.6	13.4	96.0	78.7	21.3

* Short (3½-h) sleep period for Groups I and III.

sponse for the 11 consecutive days of the experimental period.

The first group, which experienced a moderate sleep loss on the fourth day and then returned to the usual day/night routine, served as a control for the other two groups.

Figure 4 is a representation of HR data for the control group. All subjects but one (Subject 2) exhibited slightly later peak-response times for HR—on the day of the sleep loss (Day 4), on the day following the sleep loss (Day 5), or on both days—than the peak response times demonstrated for the first 3 days or the last 6 days.

The T_{re} summation dials are presented in Figure 5 for Group I. For T_{re} there were no significant changes in time of peak response for any of the subjects throughout the 11 days, not even on the fourth day, when the sleep loss occurred.

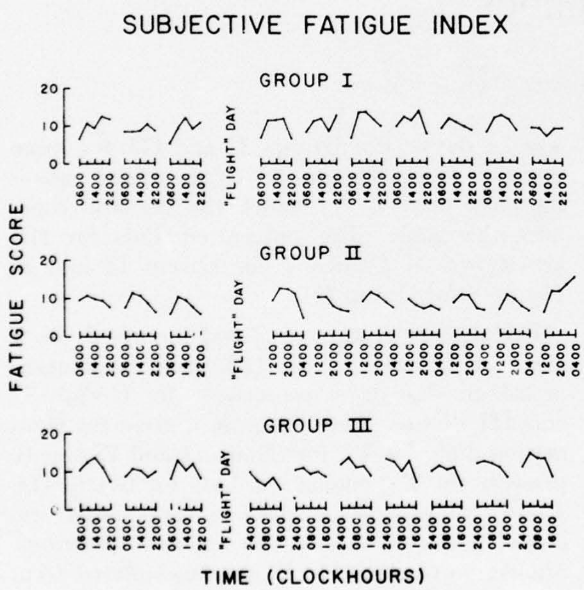

Figure 3.—Mean response of Subjective Fatigue Checklist as a function of time of day for Groups I, II, and III (n=5 for each group).

Table 3.—Daily Mean Score—Subjective Fatigue Index

	Group I	Group II	Group III
Day 1	10.2	9.5	11.0
Day 2	8.9	9.0	9.7
Day 3	9.3	8.0	10.4
Day 4*	----	----	----
Day 5	9.5	10.0	7.4
Day 6	10.2	8.2	9.7
Day 7	10.9	9.3	11.1
Day 8	10.8	7.7	10.8
Day 9	9.8	8.4	9.4
Day 10	10.3	8.0	10.6
Day 11	8.6	11.5	11.7

* Day of shift in wake-sleep cycle, fatigue indices not executed.

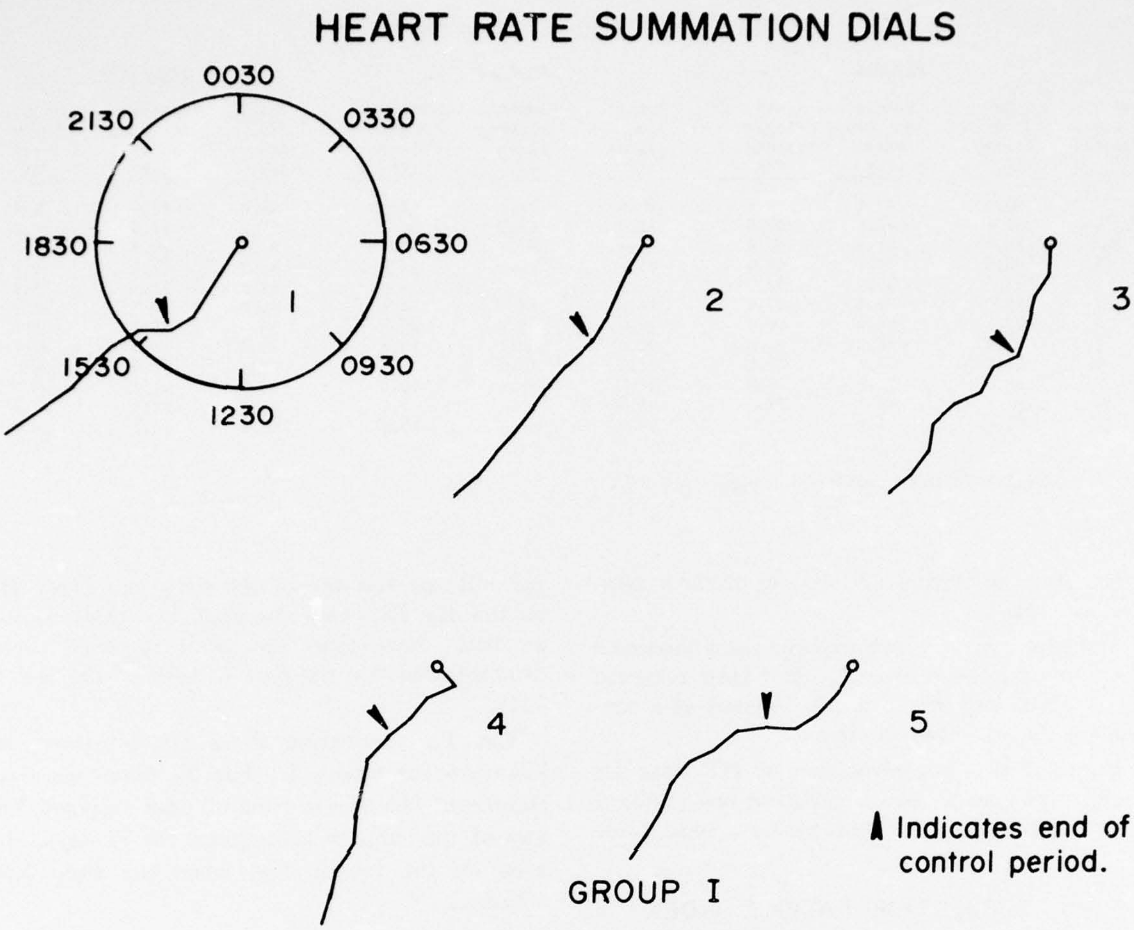

FIGURE 4.—Heart rate summation dials for Group I.

The times of peak response for HR and T_{re} are better defined than those for the urinary constituents, as the frequency of measurement was four times greater for these two parameters than for the urine. The urinary constituents for Group I, however, did evidence perturbations in the peak response pattern at Days 4 and 5. The 17-KGS, shown in Figure 6, were chosen as representative of urinary constituent data for Group I.

The moderate sleep loss at Day 4 for Group I did not result in any long-term pattern displacement for time of peak response for any of the variables studied.

Heart rate made a very rapid adjustment to new wake-sleep cycles for each of the protocols studied to date. In the previously reported 12-h-shift study, the mean rephasal time for HR was 1.4 days. For Groups II and III, the mean rephasal time was also 1.4 days. Heart rate is the only variable for which the rephasal times were the same. The summation dials for HR are shown in Figure 7 for Group II and in Figure 8 for Group III.

Rectal temperature rephasal occurred in a mean of 4.9 days for the 12-h group and means of 2.4 and 2.0 days respectively for Groups II and III of this study. Figure 9 gives the summation dials for T_{re} for Group II and Figure 10 presents the T_{re} summation dials for Group III. These two groups demonstrate very similar rephasal patterns, although in opposite directions. Subject 5 of Group II (Figure 10) suffered from a severe intestinal upset and diarrhea during the study, and his patterns are not typical of the others in the group.

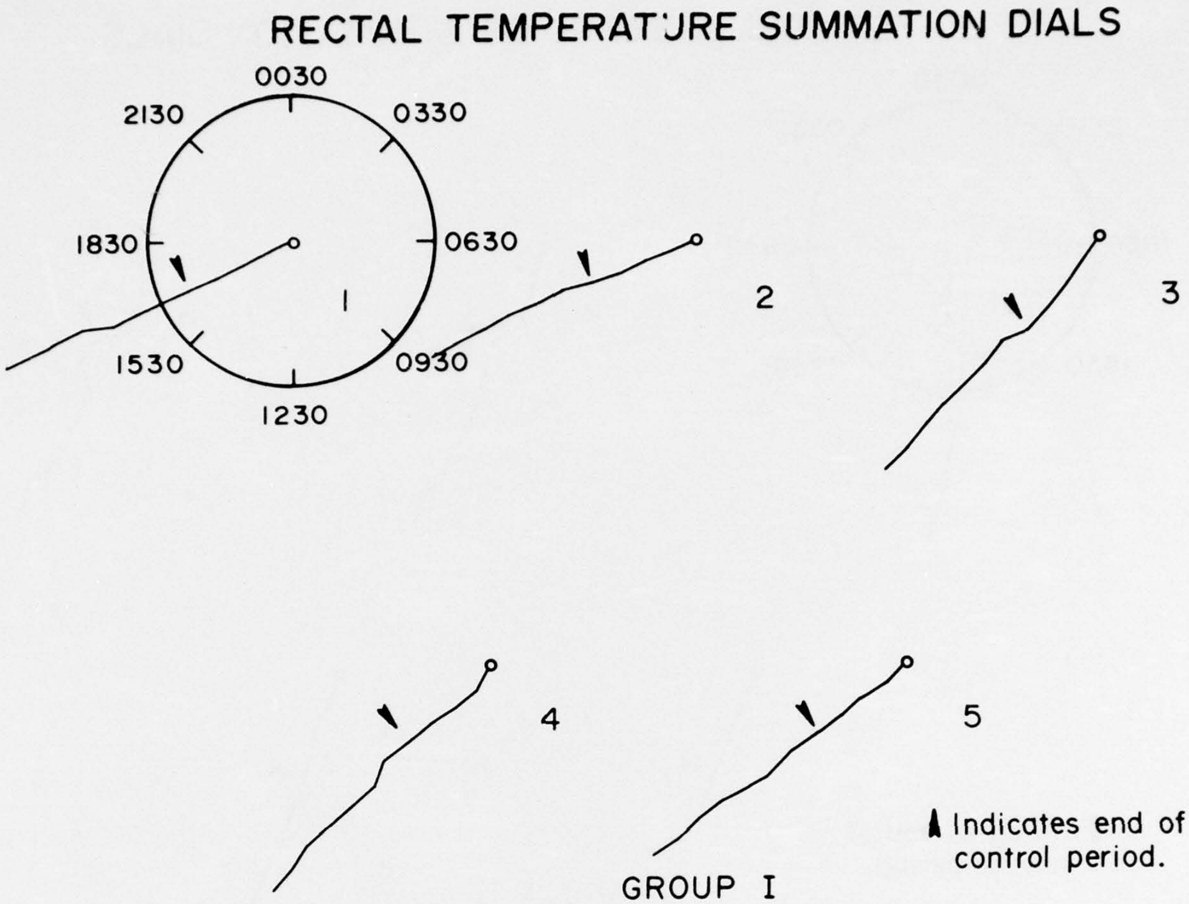

FIGURE 5.—Rectal temperature summation dials for Group I.

The urinary constituents did not present pictures for the summation dials as clear-cut as those found in the 12-h study. This difference could be due to the sampling frequency's being reduced to once each 4 h (six samples per day); in the 12-h study samples were collected each 3 h (eight samples per day). In Group II Subject 5 was ill for part of the data collection period and gave questionable results for some of the parameters; also, in Group III, Subject 4 was found to have glucose in his urine, which interfered with some of the biochemical assays, particularly the 17-KGS determinations.

The summation dials for the urinary constituents are found in the following figures: For Group II, Figures 11, 12, 13, 14, and 15 give the summation dials for epinephrine (E), nonrepinephrine (NE), 17-KGS, Na^+, and K^+ respectively; for Group III, Figures 16, 17, 18, 19, and 20 present the summation dials for E, NE, 17-KGS, Na^+, and K^+ respectively.

Psychomotor Performance. Although each individual was given 60 trial sessions on the Kugel apparatus during the training period that preceded the experimental phase of these studies, the learning effect was still apparent to the end of the experiment. Even though the mean daily scores showed little or no improvement from Day 7 to 9 for all three groups, scores again increased on Days 10 and 11. The results of the psychomotor performance task are presented in Figure 21 and Table 4. Patterns for peak performance at a given time of day were not readily apparent. However, in general, the first performance of the day was the poorest for all groups on the first 3 days when the subjects were

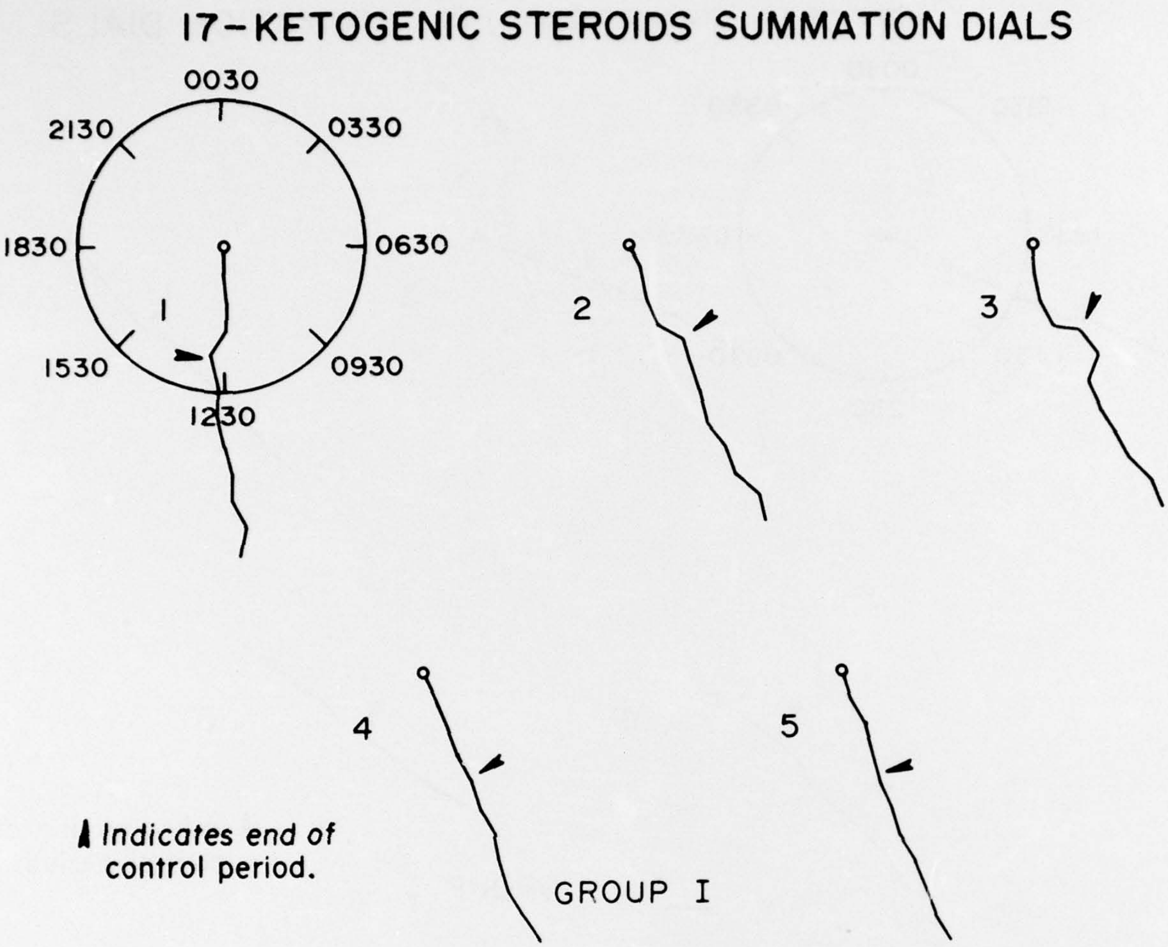

FIGURE 6.—17-ketogenic steroids summation dials for Group I.

all sleeping from 2230 to 0600 and was usually the poorest performance score for Group I through the remainder of the experiment. For Group II, the poorest performance of the day was also the first performance, although after the change its first session was at 1300. For Group III the poorest performance after the shift was either the third or fourth session of the day, which occurred at 0800 and 1300. On the last 2 days of the experiment, however, Group III had its poorest performance the first session of the day, which was at 0100.

Multiple Task Performance Battery. The composite scores for multiple task performance were broken down into 3-day blocks for purposes of analysis. The blocks are the 3 days prior to the time shift, the 3 days directly following the time shift (Days 5–7), and the next 3 days (Days 8–10). The final day of testing, Day 11, was dropped from the analysis because of the expected "end spurt" effect and because of missing data for some groups. The data for these 3-day blocks are shown graphically in Figure 22.

Each 3-day block of data was subjected to a Lindquist Type VI analysis of variance.[9] In these analyses, the following sources of variance were identified: (1) subjects, (2) groups, (3) between subjects within groups, (4) within subjects, (5) sessions (four per day), (6) periods (two per session), (7) sessions x periods, (8) sessions x groups, (9) periods x groups, (10) sessions x periods x groups, and (11) appropriate error terms for the within-subject effects. The probability values for each of the main and interaction effects for each analysis are summarized in Table 5. The only significant dif-

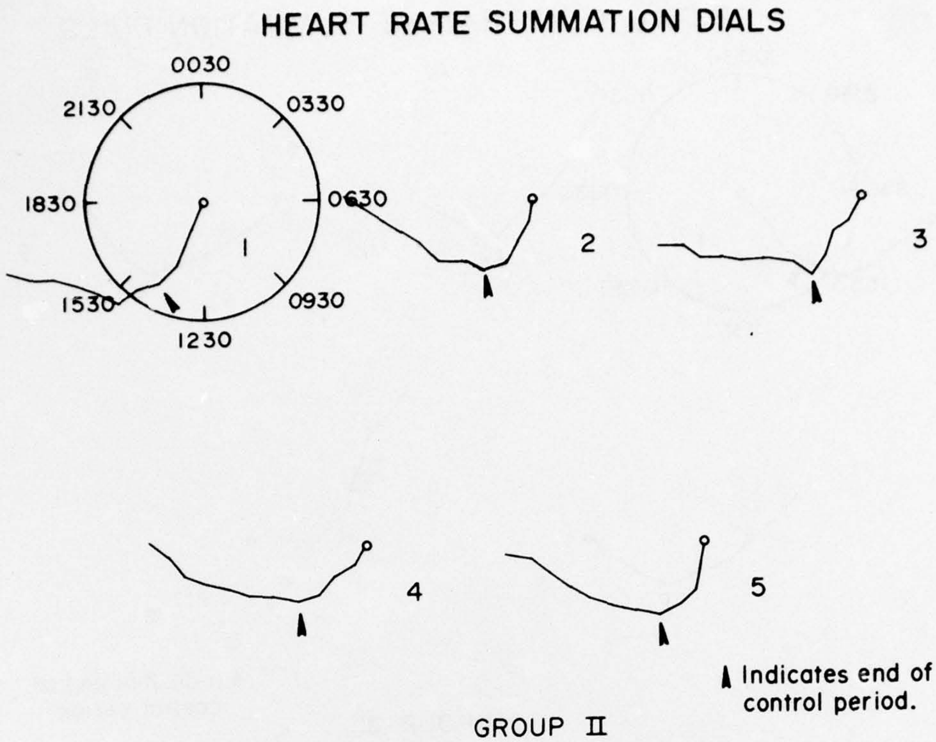

FIGURE 7.—Heart rate summation dials for Group II.

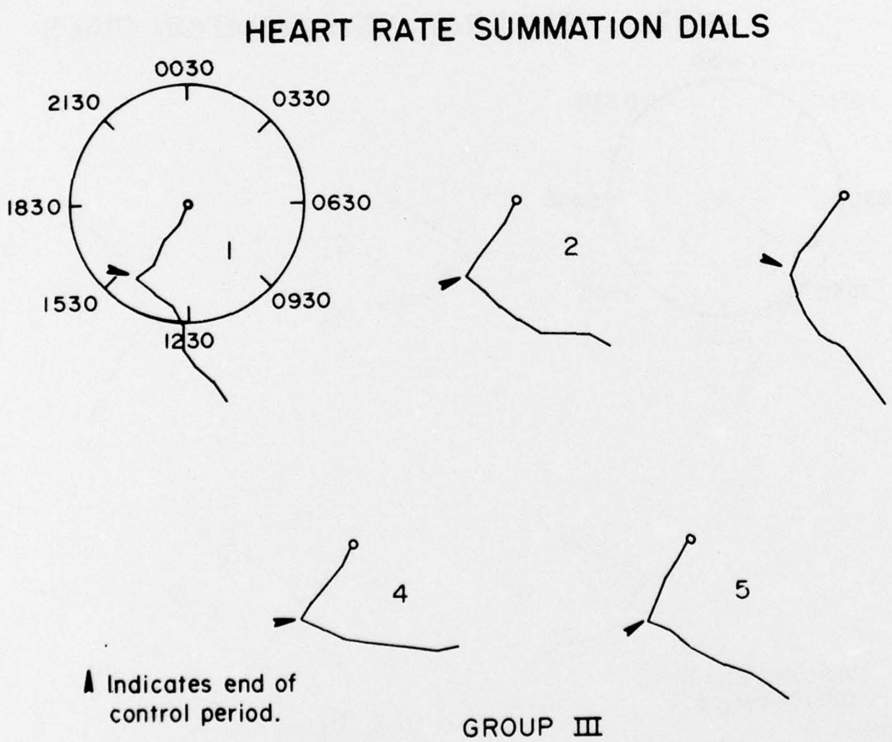

FIGURE 8.—Heart rate summation dials for Group III.

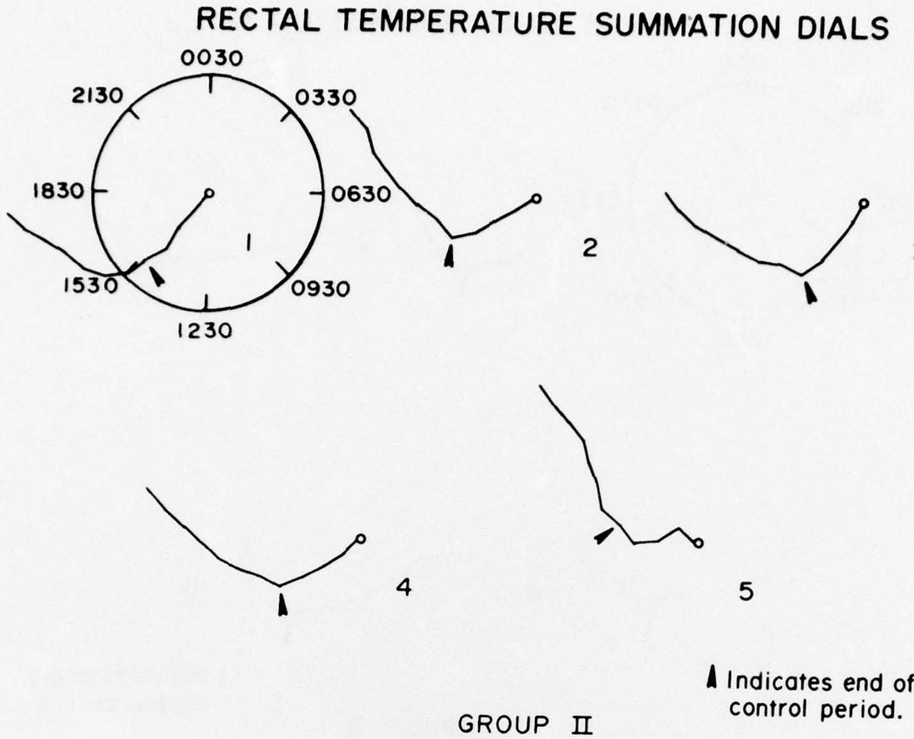

FIGURE 9.—Rectal temperature summation dials for Group II.

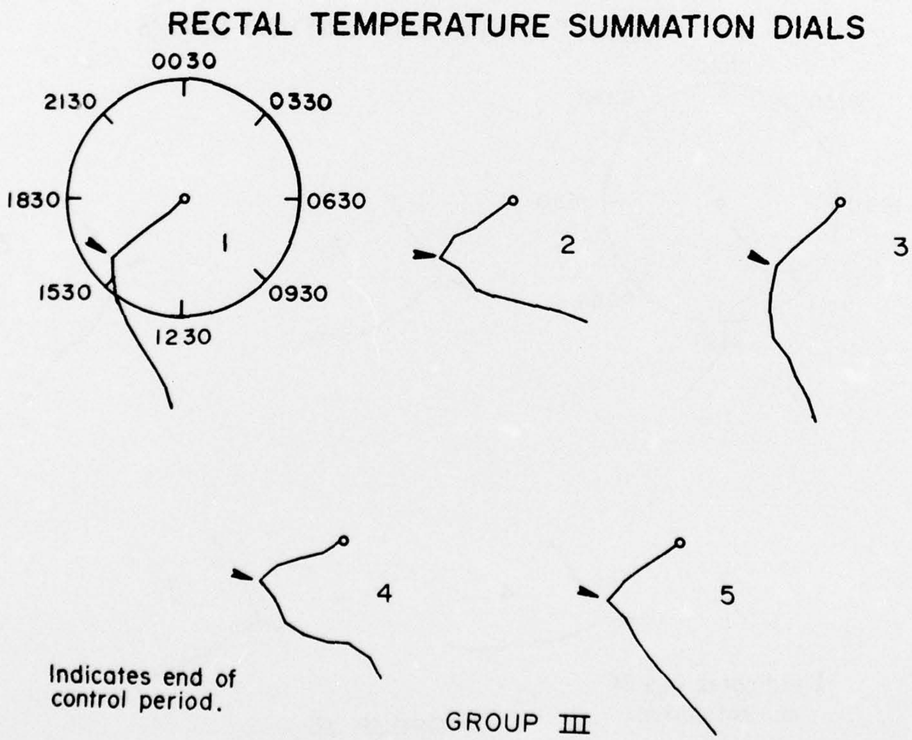

FIGURE 10.—Rectal temperature summation dials for Group III.

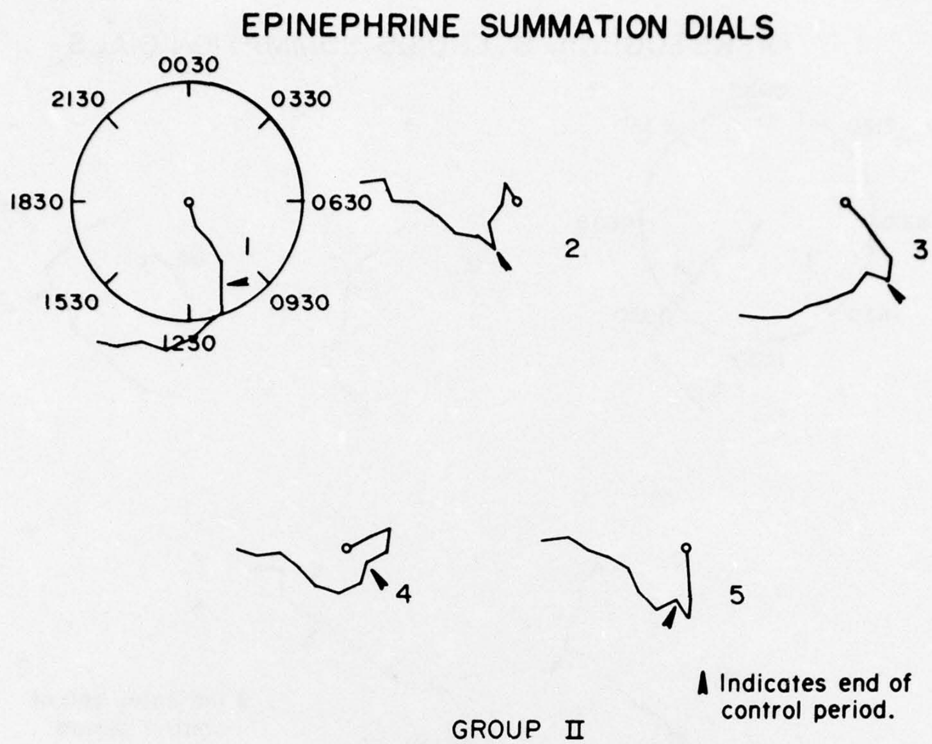

FIGURE 11.—Epinephrine summation dials for Group II.

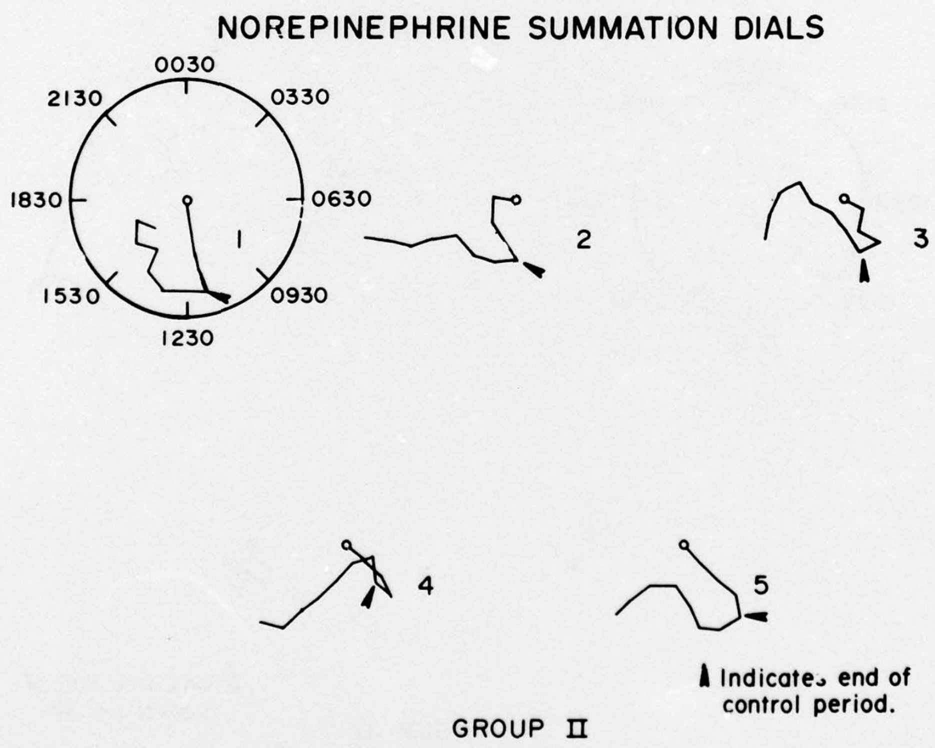

FIGURE 12.—Norepinephrine summation dials for Group II.

17-KETOGENIC STEROIDS SUMMATION DIALS

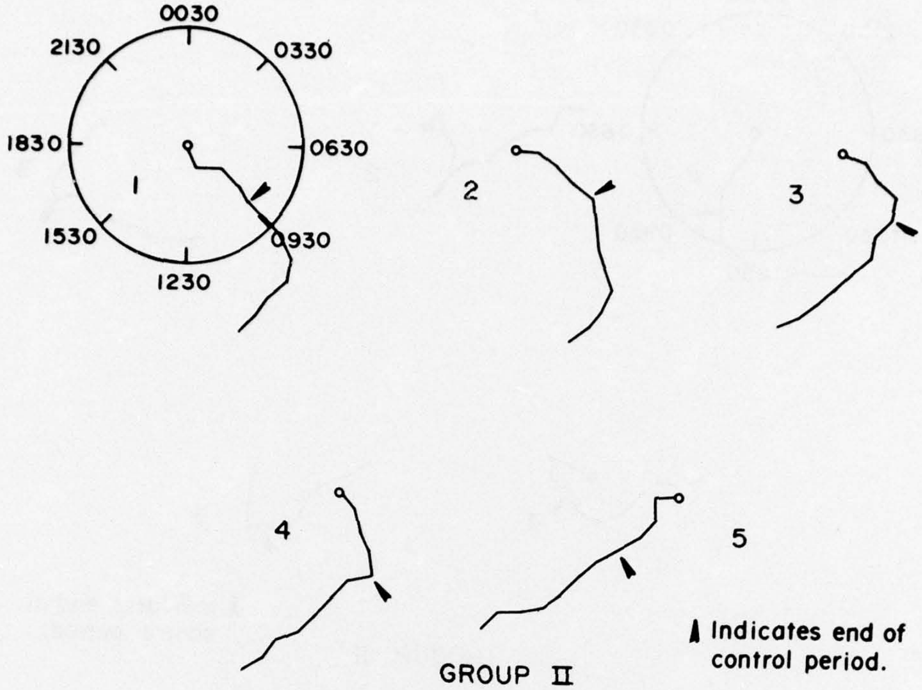

FIGURE 13.—17-ketogenic steroids summation dials for Group II.

SODIUM SUMMATION DIALS

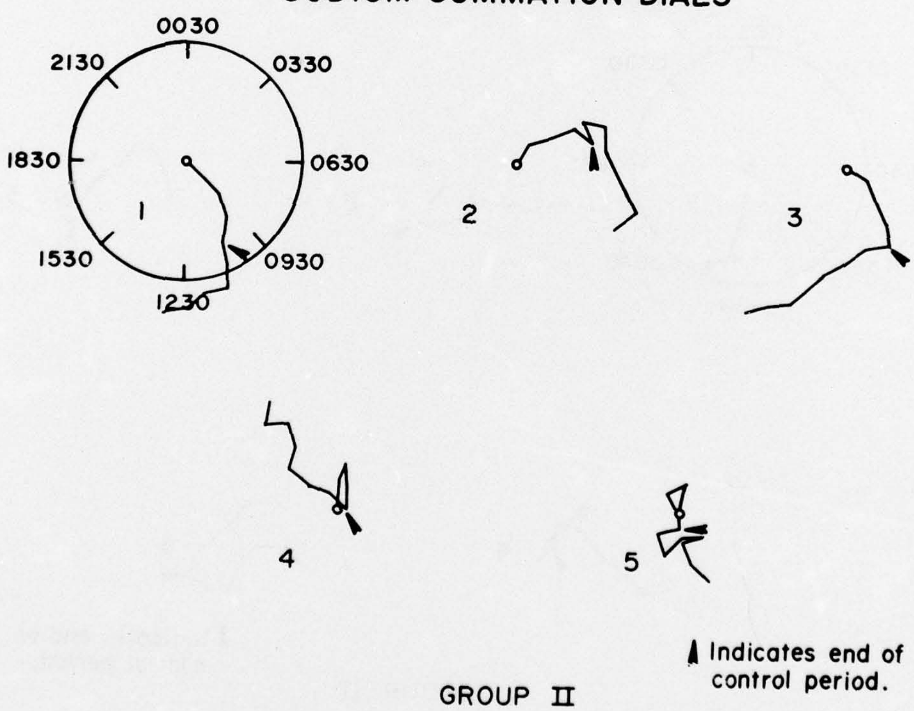

FIGURE 14.—Sodium summation dials for Group II.

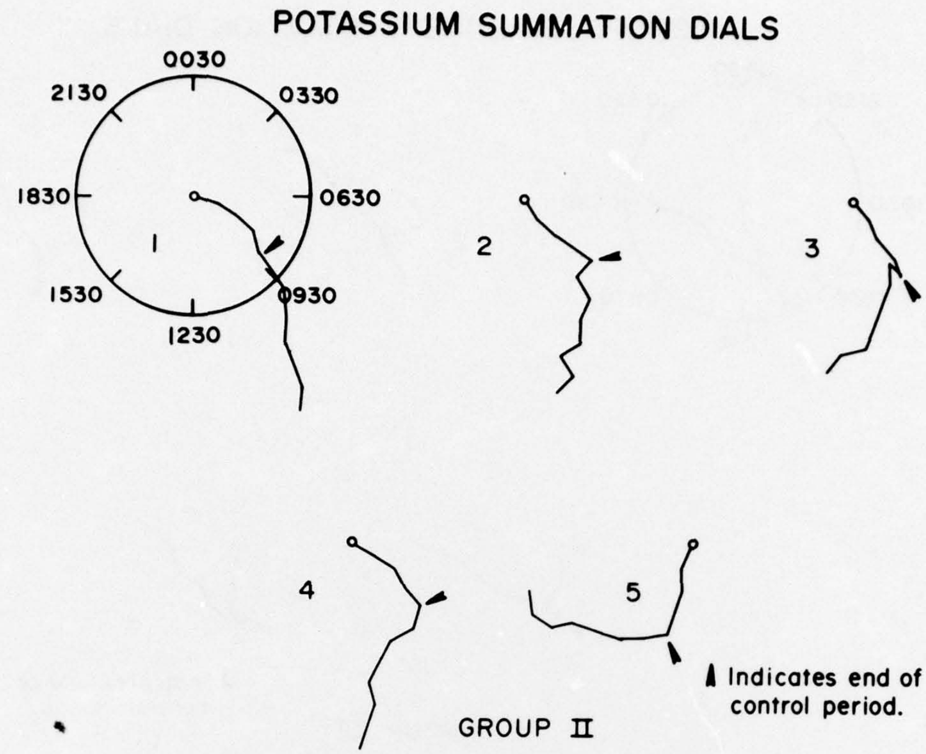

FIGURE 15.—Potassium summation dials for Group II.

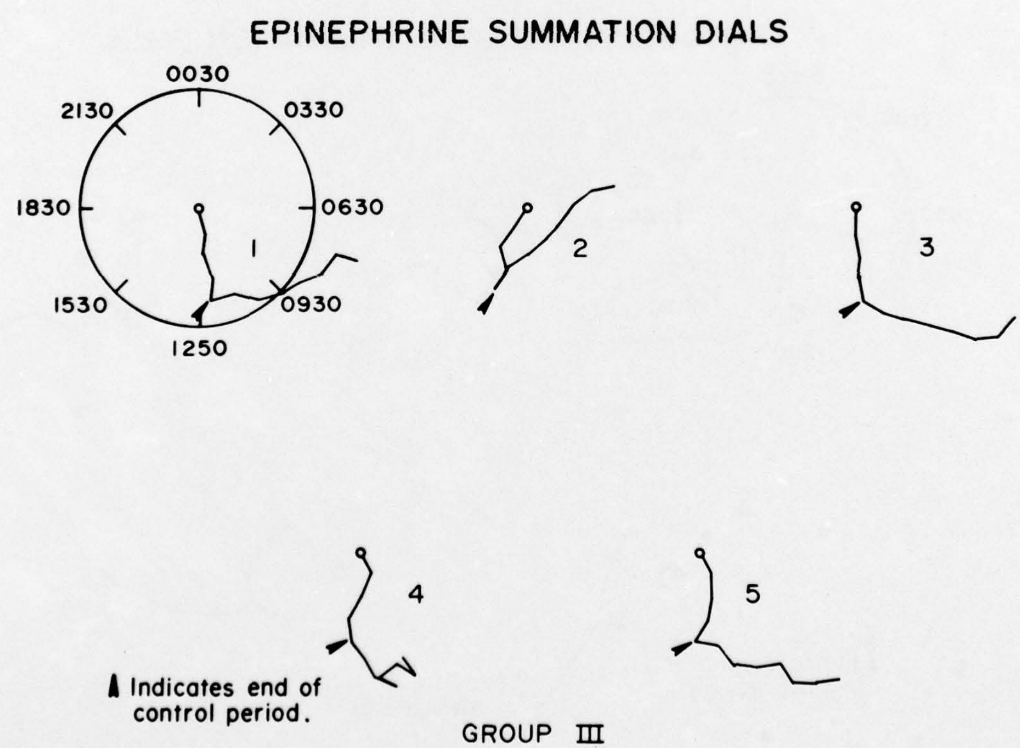

FIGURE 16.—Epinephrine summation dials for Group III.

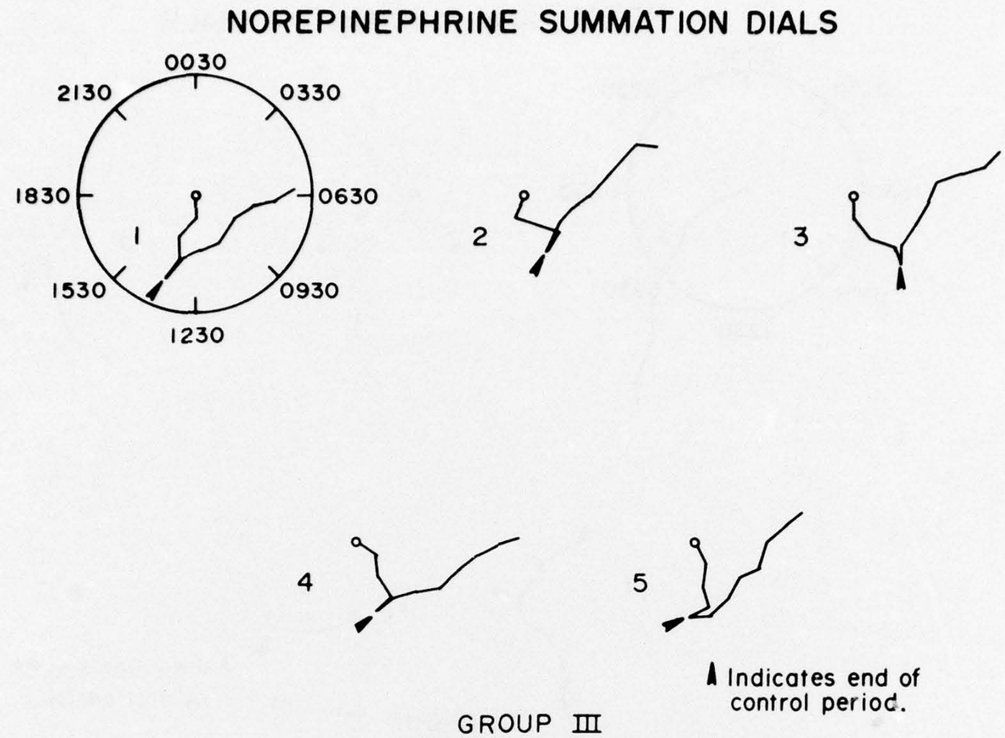

Figure 17.—Norepinephrine summation dials for Group III.

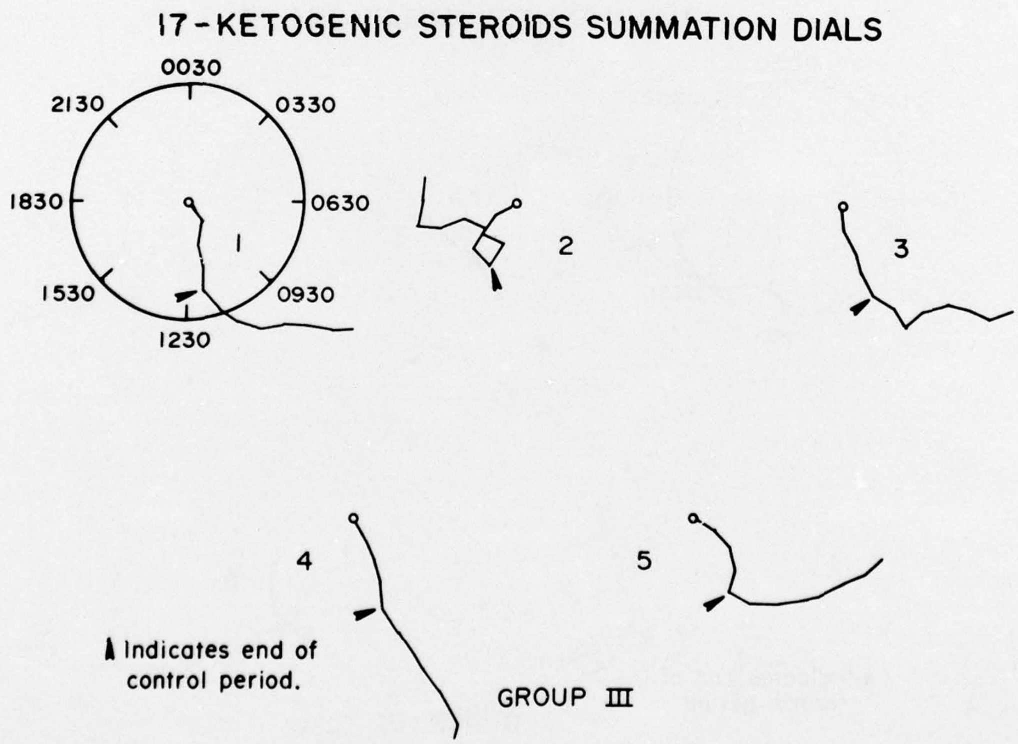

Figure 18.—17-ketogenic steroids summation dials for Group III.

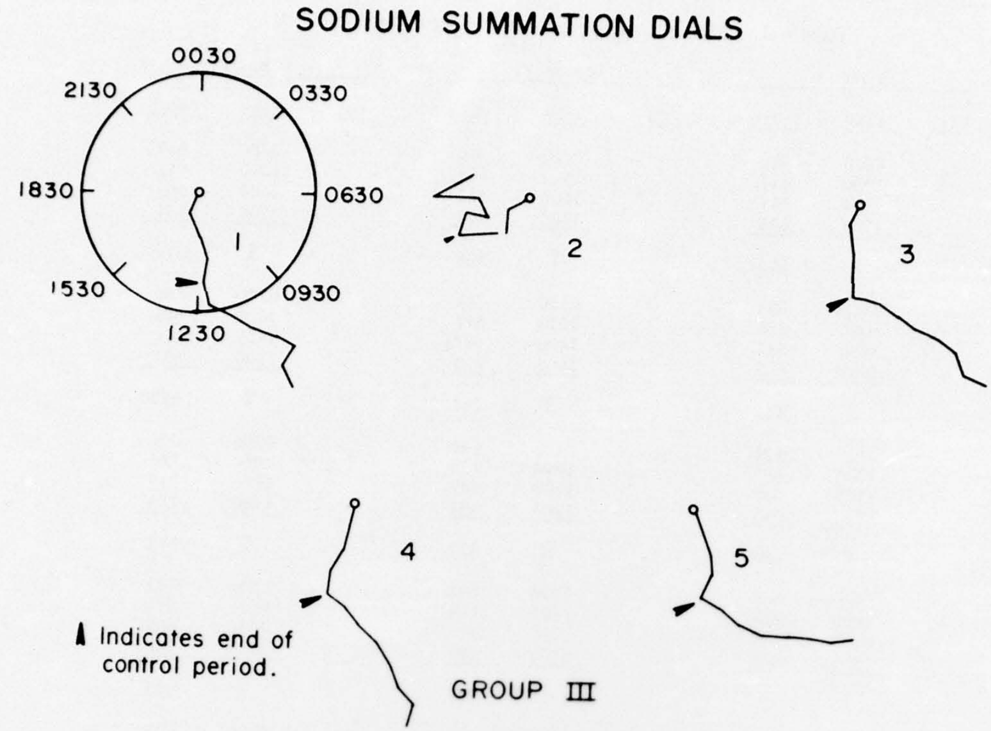

FIGURE 19.—Sodium summation dials for Group III.

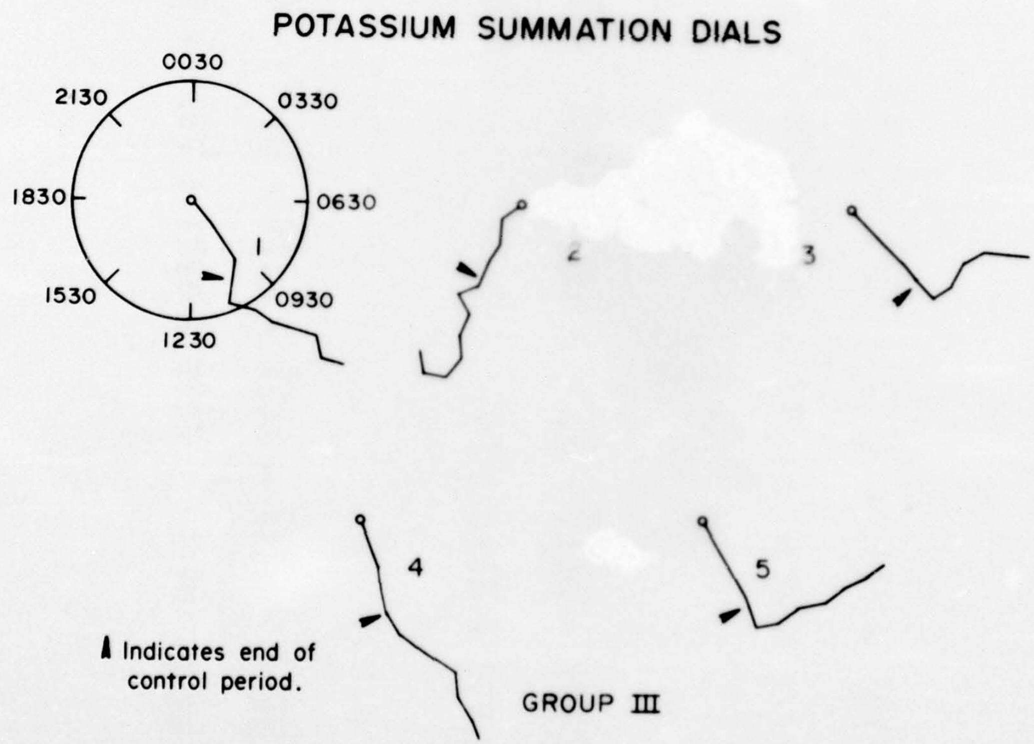

FIGURE 20.—Potassium summation dials for Group III.

Table 4.—Mean Psychomotor Performance Scores

Group I			Group II			Group III		
Day	Time	Score	Day	Time	Score	Day	Time	Score
1	0700	629	1	0700	545	1	0700	646
	1000	641		1000	608		1000	681
	1400	647		1400	562		1400	669
	1900	655		1900	542		1900	691
	$\bar{X}$	643		$\bar{X}$	564		$\bar{X}$	672
2	0700	663	2	0700	562	2	0700	660
	1000	658		1000	597		1000	696
	1400	631		1400	597		1400	678
	1900	665		1900	615		1900	692
	$\bar{X}$	654		$\bar{X}$	593		$\bar{X}$	682
3	0700	671	3	0700	591	3	0700	696
	1000	695		1000	635		1000	726
	1400	695		1400	627		1400	715
	1900	695		1900	653		1900	733
	$\bar{X}$	689		$\bar{X}$	627		$\bar{X}$	718
5	0700	666	5	1300	622	5	0100	731
	1000	688		1600	666		0400	693
	1400	691		2000	674		0800	604
	1900	690		0100	666		1300	702
	$\bar{X}$	684		$\bar{X}$	657		$\bar{X}$	683
6	0700	681	6	1300	652	6	0100	711
	1000	690		1600	683		0400	728
	1400	692		2000	676		0800	643
	1900	689		0100	676		1300	732
	$\bar{X}$	688		$\bar{X}$	672		$\bar{X}$	704
7	0700	688	7	1300	660	7	0100	759
	1000	693		1600	699		0400	751
	1400	704		2000	685		0800	745
	1900	713		0100	691		1300	736
	$\bar{X}$	700		$\bar{X}$	684		$\bar{X}$	748
8	0700	699	8	1300	680	8	0100	782
	1000	708		1600	673		0400	753
	1400	689		2000	681		0800	703
	1900	709		0100	683		1300	715
	$\bar{X}$	701		$\bar{X}$	679		$\bar{X}$	738
9	0700	697	9	1300	670	9	0100	756
	1000	721		1600	676		0400	766
	1400	715		2000	719		0800	727
	1900	722		0100	689		1300	725
	$\bar{X}$	714		$\bar{X}$	689		$\bar{X}$	744
10	0700	737	10	1300	710	10	0100	742
	1000	733		1600	700		0400	777
	1400	741		2000	723		0800	751
	1900	735		0100	689		1300	743
	$\bar{X}$	737		$\bar{X}$	706		$\bar{X}$	753
11	0700	729	11	1300	693	11	0100	737
	1000	755		1600	729		0400	771
	1400	753		2000	724		0800	773
	1900	773		0100	701		1300	776
	$\bar{X}$	753		$\bar{X}$	712		$\bar{X}$	762

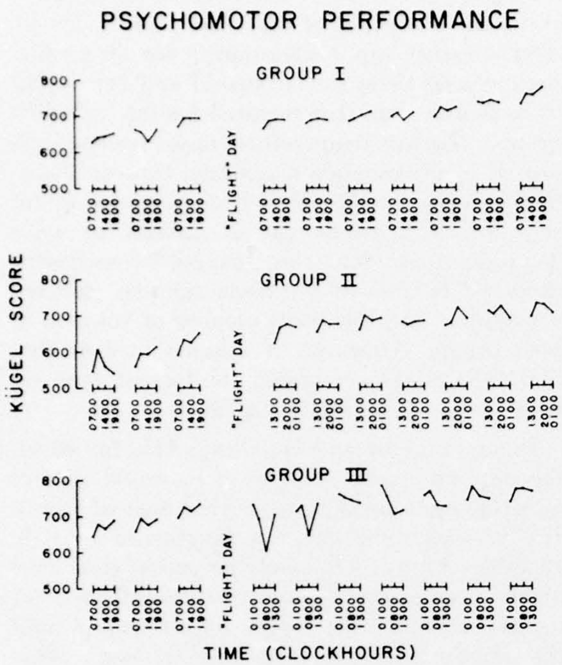

FIGURE 21.—Mean Psychomotor Performance scores as a function of time of day for Groups I, II, and III (n=5 for each group).

ference between groups was in the preshift data; this result is clearly an artifact of the reduction of the between-subjects variance to essentially zero for the preshift phase caused by the method of computing the composite scores. For all three phases of the experiment, the sessions effect and the interaction of sessions and groups were significant at the .01 level of confidence. The sessions x periods and the sessions x periods x groups interactions were significant in the two postshift 3-day blocks ($p \leq .01$). The periods effect was significant for the preshift ($p \leq .01$) and the Days 8–10 blocks ($p \leq .05$), and the periods x groups interaction was significant for the first postshift block ($p \leq .01$). The general picture that emerges from examination of the figures is that on the average, Group II (east-west) was least affected by the shift; in fact, throughout the study, performance was arithmetically better maintained by Group II than by the control group. Because of the significant triple interaction for both the postshift blocks, interpretation of the sessions x groups interaction is difficult; however, the daily pattern of changes over sessions generally was different for the three groups. On the average, the performance of Groups I and III declined over the

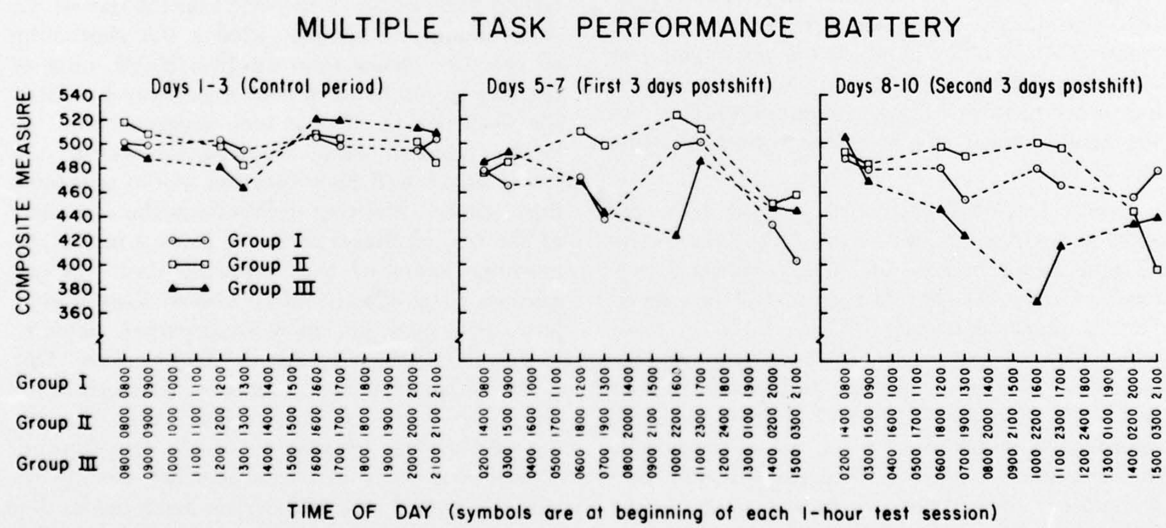

FIGURE 22.—Multiple Task Performance Battery mean composite performance scores as a function of time of testing for Groups I, II, and III, for the control period, the first 3 days postshift and the second 3 days postshift (n=5 for each group).

TABLE 5.—Summary Table of p Values from Analyses of Variance

	Pre	Post 1-3	Post 4-6
Groups	.01	---	---
Sessions	.01	.01	.01
Periods	.01	---	.05
Sessions x Periods	---	.01	.01
Sessions x Groups	.01	.01	.01
Periods x Groups	---	.01	---
Sessions x Periods x Groups	---	.01	.01

course of the experiment whereas, with the exception of the final session of the day, the performance of Group II was maintained essentially at the preshift levels for the postshift blocks of the study.

IV. Discussion.

Subjective Forms. The results of the sleep survey seem to indicate good adjustment on the part of the subjects to the laboratory setting. Group I consistently reported a lower percentage of sleep during the sleep periods. However, the lower mean was due primarily to one individual (Subject 2) of this group. He reported sleeping only about 48 percent of the sleep periods during the control days, about 45 percent during the first 4 days after the "flight" day, and 80 percent during each of the last 3 days of the experiment. On the other hand, he did not report any subjective feeling of fatigue greater than that of any other member of the group, nor were any of his physiological or biochemical measurements out of line.

Group I subjects demonstrated the least impact on their daily mean score of the Subjective Fatigue Index because of the experimental protocol. Group III showed the greatest fatigue on Day 5 immediately after the change in their wake-sleep cycle; however, these subjects appeared to recuperate quickly and return to control levels. Group II subjects, on the other hand, appeared to suffer greater fatigue in the middle of the postshift period. The psychomotor performance scores appear to verify some of the fatigue results; i.e., Group II's performance actually improved 4.8 percent from Day 3 to Day 5, while Group III declined in performance 4.7 percent from Day 3 to Day 5.

Physiological and Biochemical Responses. With the exception of HR data, which demonstrated rather rapid adjustments for all groups, the rephasal times for Groups II and III appear to be shorter than that required for the 12-h-shift group. Rectal temperature measurements appeared to demonstrate a rephasal time only one-half as long for the two 6-h-shift groups as for the 12-h-shift group. It is difficult to make determinations for the urinary constituents measured because of the fewer samples collected per subject and the small number of subjects in each group. However, it appears evident that the 17-KGS again required the longest rephasal time of those parameters measured.

It was anticipated that Group III, for which the day was compressed by 6 h, would require an adjustment period greater than that of Group II, for which the day was lengthened by 6 h. In other studies[2,7,8,12] involving actual time zone displacements, the groups traveling from west to east demonstrated longer adjustment periods than those traveling from east to west. This was not the case for our T_{re} measurements, nor was it discernible from the other physiological and biochemical measurements. There were evidences of this reported trend in the fatigue indices, the psychomotor performance task, and the MTPB results. Perhaps, the adjustment of physiological parameters was facilitated by Group III's 3½-h sleep period on the day of the shift change. This permitted a 6-h shortening of the day rather than an 18-h lengthening of the day as might have been experienced without the sleep period. It has been suggested that the longer rephasal times required for west-to-east travel could well be a function of the scheduled flight times. Evening flights from the east coast of the United States arrive in Europe in the late morning hours of the following day. If one assumes little effective sleep aboard these flights, passengers miss one entire sleep period. This is, of course, always true for the flight crews. One study[2] suggests that for humans, lengthening of the day is a more normal response than shortening of the day, because results of free-running experiments (ones in which all time cues are removed) show more individuals tend to develop rhythms greater than 24 h. The same study[2] also suggests that sleep obtained in late afternoon and early evening hours, when activity levels are normally at their highest, is less effective than sleep obtained in early morning hours, when activity levels are normally reduced.

In any event, the results of the physiological and biochemical measurements in our study do not correspond to those of time zone displacement studies; they do indicate that perhaps the change in the wake-sleep cycle experienced by a shift worker does not have the same effect on physiological responses as the change experienced by a traveler who is displaced to a new time zone.

Psychomotor Performance. Psychomotor performance gave a greater indication of differences between Groups II and III than did the physiological and biochemical measurements. Group II's performance was similar to that of the control group (Group I) the first day after the change in the wake-sleep cycle in that the poorest performance of the day was the first test after awakening from the sleep period. It was not until the last 2 days that Group III showed its poorest performance the first period after awakening. Although the sleep surveys yielded no indication, perhaps the quality of sleep obtained by Group III was not equivalent to that of Group II.

Multiple Task Performance Battery. The interpretation of the effects of the time shift on multiple task performance must be conditioned by two factors. First, the subjects in Group II were permitted a sleep period of normal duration immediately prior to the postshift phase of the study, whereas the subjects of Groups I and III had short ($3\frac{1}{2}$-h) sleep periods prior to the shift. Second, discussions with the subjects strongly suggested that most of them considered themselves to be "night people"; thus, a shift west would be more like their normal schedule and a shift east would be further from their normal schedules than would appear simply on the basis of clock time.

The preshift performance curves are about typical of what would be expected, although the magnitude of the fluctuations was greater for Groups II and III than for Group I. Generally, the subjects showed declining performance during the morning hours, reached a low point after the lunch break, and showed relatively high levels of performance during the late afternoon and early evening performance sessions.

During the 3-day block immediately following the shift, Groups I and III showed similar performance curves that could be described in part as exaggerations of their preshift performance. The main difference is seen in the pronounced drop in performance during the final 2 hours of the day. The results for these two groups are probably most parsimoniously explained as reflecting a residual effect of the loss of sleep experienced prior to the shift. During this same period, the performance of Group II could be described as reflecting directly the 6-h shift in the day. The performance of these subjects appears to start the day at about the level maintained during the postlunch session of the preshift block. Their performance improved somewhat through the day, but they showed a marked drop in performance at the end of the day. In this respect, all three groups performed as though the total period of wakefulness had been lengthened, with a resultant increase in the buildup of fatigue.

During the final 3-day block, the performance of the subjects in the control group returned to approximately the levels maintained prior to the shift phase of the experiment. However, there was an increase in the magnitude of the session-to-session fluctuations. Group III, the "eastbound" group, showed the poorest performance during the 1-h period that began 3 h later (local time) than the period of lowest performance during the preshift phase of the experiment, but the end-of-day depression of performance found during the first 3 days postshift was not present; instead, the group's performance improved relative to the low point of the curve. Overall, the performance of this group was the poorest of the three. The "westbound" group, Group II, maintained a fairly stable level of performance during the first three sessions of the day during this phase but still exhibited the substantial end-of-day performance deficit.

The time base for Figure 23 is such that, if complete adaptation had taken place, the curves for Groups II and III should have been "identical" to the curve for Group I. Clearly they are not, as evidenced by both the curves and by the significant sessions x groups interaction. Since the curve for Group I was approximately of the same form during the final 3 days that it was during the preshift phase, it appears that the effects of the sleep loss on the shift day had been dissipated. Unfortunately, the possibility that the same was not true for Group III precludes our drawing unequivocal conclusions about the performance effects of the experimental manipulation of the time variable. However, it does seem clear that the performance of the "westbound" group did not reflect adaptation to the new time schedule, and, although it is much less clear, it also seems likely that the "eastbound" group did not adapt in the course of the study.

Overall, the multiple-task-performance data on the one hand and the physiological and biochemical data on the other lead to different conclusions about the adaptation of the subjects to the two different time shifts. We can offer no explanation for this discrepancy; apparently, different processes are involved as higher order determinants in the two spheres of measurements.

V. Conclusions.

Because of the small sample number and the wide individual variability in this study, it is difficult to draw definitive conclusions.

According to the physiological and biochemical measurements there is little difference between the two 6-h-change groups, both of which required longer rephasal times than did the group with sleep loss but no time change.

The psychomotor performance test indicates the greatest change in the group with the day shortened by 6 h.

The complex performance task (MTPB) indicates the greatest deficit in performance for the group with the day shortened (west to east) by 6 h and the best postshift performance by the group whose day was lengthened (east to west) by 6 h. Therefore, if performance of the type represented by the MTPB is the most important consideration, then travel from west to east (or "quick turnarounds" for shift workers) appears to be more deleterious than the opposite occurrences. However, this cannot be predicted on the basis of the physiological and biochemical determinations made in this study.

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Rectal temperature
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